with the Authors Compts

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THE CONSTITUTION OF MATTER.

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Since the human race first came into existence, men have been more or less occupied with the study of natural philosophy; pursuing it either in the character of professed philosophers, or more usually in the manner of simple wondering observers, like the shepherds of ancient story. Whilst contemplating natural phenomena,—the progress of the seasons, the propagation and growth of herbs and animals, or the properties of earths and metals,—the inclination, apparently instinctive, has ever been to look for something behind the mask of nature; to endeavour, in other words, to find reasons for the existence of things as they are; to seek for other phenomena of a simpler and yet more general nature, which are considered to be what are usually denominated the "causes."

To what extent this endeavour has been successful it is difficult to ascertain, much more to express. According to all probability, in this search after causes, we pursue a will-o'-the-wisp, which possesses no real existence,—a difficulty, indeed, presenting itself at the outset, it having even been found impracticable to explain or define accurately what is meant by the term "cause." The philosophers who have through ages applied themselves to the study of effects and causes, seem to have neglected this fundamental inquiry. In connection with such a study, it would be worth consideration whether the entire universe may not be the great proximate and ultimate cause of itself; every fraction of it exercising such an influence upon every other fraction, and, upon the whole, as to be indispensable to the existence and integrity of the natural order of things. However, this may be, the chemists and physicists, even before the departments of science which they respectively practise assumed independent existence, have ever been looking, like the rest of mankind, for what they suppose to be the causes of the phenomena which they specially study. As they occupy themselves with matter and its associated qualities, it has arisen that they have devoted all available ingenuity to the explanation of the sensible properties of matter by speculations as to its ultimate and final constitution. The oldest of the theories founded on such speculations is that which has held its ground the longest; not altogether because it is perfect and unassailable, but chiefly, as I shall endeavour to show, from its possessing this recommendation, that it makes use of things which we can see and touch, in order to represent and symbolize things which cannot be thus tried by the test of the senses.

The mind constantly endeavours to account for unfamiliar phenomena, by drawing a parallel between them and others which are more perfectly understood. According to the view referred to, all kinds of matter are imagined as composed of "massy, hard, impenetrable, moveable particles, of such sizes and figures as best conduced to the end for which they were formed." This atomic theory, in its physical phase, was known, literally, ages ago; it was a subject which occupied the discussions of the Greek, and even the Hindoo philosophers; it is referred to by Newton in the often-quoted passage in his 'Opticks;'

but it was reserved to Dalton, at the beginning of the present century, to revive the problem and to perceive how the idea of atoms or finite particles might be applied to the explication of the phenomena of chemical combination. Notwithstanding, however, the great credit due and awarded to Dalton for his acuteness, it was only by the discoveries of observers subsequent to him that the hypothesis was consolidated into a theory of stability. The only experimental data possessed by Dalton were the facts that the instances then known of chemical combination exhibited the definite character, which has since been traced out in thousands and tens of thousands of cases. They were limited to such combinations as the oxides of carbon, nitrogen, sulphur, and those of a few of the metals, and were based upon analyses which, although pretty good considering the state of chemical knowledge at the time, were, nevertheless, extremely inaccurate. The data for the law of multiple proportions were in the hands of several chemists before Dalton's time, particularly Proust; the law of reciprocal proportions was also partially discovered, but never enunciated, in the last century by Richter; we cannot therefore help admiring the clear-seeing sagacity, as well as the boldness of Dalton, in giving to the world an explanation which so many had failed before him to perceive. It must, however, be confessed that the conclusions of Dalton's own mind were maintained by him somewhat dogmatically, when we consider what is really the truth, that his theory does not follow as a logical necessity from the facts known to him.

We have learnt from observation, and a long series of thousands of experiments, that, in nearly all cases of chemical combination, the compounds formed consist of definite and invariable proportions by weight of the constituents employed. This is the leading fact which cannot be disputed. A study of its different features has led to three great general statements, known as the *law of definite proportions; the law of reciprocal proportions;* and *the law of multiple proportions.*

The first of these is simply an enunciation of the rule just stated: "Thus, water, which consists of one part by weight of hydrogen united to eight parts of oxygen, cannot be formed by the same elements in any other than these proportions. You can neither add to nor subtract from the normal ratio of the elements without entirely altering the nature of the compound."

It must be stated, however, that all the best and most careful experiments have been made only upon the simplest compounds, such as metallic salts. It yet remains to be proved whether there are not numerous instances of combination occurring in indefinite proportions. There seem to be instances of such combination when the attraction between the uniting elements is of a feeble character.

The second law quoted asserts that when chlorine, for example, unites with oxygen and with carbon, the proportions of oxygen and carbon in the compounds so formed are those in which they will themselves unite together, or, as the law of multiple proportions tells us, are simple multiples or fractions of those proportions. Upon these three "laws," which, be it observed, are merely general formulæ expressing what had been observed in a number of individual instances, Dalton based his atomic theory, explaining the combination of masses of matter in invariable proportions by the hypothesis of their being constructed of particles of definite size and weight and indivisible. As before observed, this cannot be *directly* inferred. "All which observation teaches us is, that if there be such particles they are smaller than the smallest observable quantities." At the present day, however, we may safely say that there are few, if any, chemists who believe as implicitly in the atoms of Dalton as he did himself. Dalton seems to have been utterly uncompromising in his notions on this matter.

He even explains such phenomena as "the opacity of metals and their lustre" by the hypothesis that "a great quantity of solid matter and a high condensation of heat are likely to obstruct the passage of light, and to reflect it." The really valuable portion of Dalton's work was the discovery of the laws of multiple and reciprocal proportion.

The atomic theory is now received as the basis of a most valuable method of expressing, in a manner intelligible to the mind, a vast body of facts, and giving the whole a systematic form. "The real experimental import of the equivalent numbers is the expression of the proportional and relative weights of bodies in which they produce equivalent effects in chemical combinations, and these effects *we represent to our minds and render intelligible* by ascribing them to indivisible particles or 'atoms' which occupy a certain space, and possess a certain form or shape."* So that the idea is employed simply as a metaphor. When we begin to inquire what these atoms are which are so freely handled and discussed, what is their nature, are they really indivisible ultimate particles? we are led away into another region into which chemistry can follow with but halting steps, if at all.

The President of the Chemical Society has recently been giving an elaborate defence of the atomic theory; it cannot but be surmised that there exists at the present time more than a small amount of disaffection from the theory, or such a defence could not have been called for.

It will be useful to recall the principal properties of matter, by the study of which the idea of atoms has been gradually established in the minds of chemists. We have seen that Dalton's belief in the existence of indivisible particles was founded solely upon a knowledge of the laws of definite chemical combination by weight. The results of analyses before Dalton's time were represented in numbers which expressed the parts of each constituent in 100 of the compound. For example, in red oxide of copper there are in 100 parts proportions as follows:—

Copper	88·8
Oxygen	11·2
	100 0

In black oxide of copper:—

Copper	79·87
Oxygen	20·13
	100·00

In carbonic oxide:—

Carbon	42·85
Oxygen	57·14
	100·00

In carbonic acid gas:—

Carbon	27·27
Oxygen	72·72
	100·00

Dalton discovered reciprocal and multiple proportions by stripping from them the disguise in which this mode of representing composition enveloped them. For by taking some one of the elements in a compound as unity, and ascertaining by calculation the proportions which the others bear to it, it is easy to show that these proportions are simple multiples one of the other.

In the instance of the two oxides of carbon, the composition of which has just been stated, if we calculate the ratio of the oxygen to the carbon in both of them, we find the proportion in the second double that in the first. Thus taking the carbon as unity :—

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* Liebig's Letters, p. 103.

	Carbon.		Oxygen.		Carbon.		Oxygen.
	42·85	:	57·14	::	1	:	1·33
And	27·27	:	72·72	::	1	:	2·66
Then plainly—							
	1·33	:	2·66	::	1	:	2

In other words, the proportion of oxygen in carbonic acid gas is double that contained in carbonic oxide. It must not be forgotten that there is another way of expressing the same fact, for by taking the oxygen as unity, instead of the carbon, we get the following proportions :—

	Oxygen.		Carbon.				
	57·14	:	42·85	::	1	:	·750
	72·72	:	27·27	::	1	:	·375
Then							
	·750	:	·375	::	2	:	1

Or we may say carbonic acid contains half as much carbon as carbonic oxide. Similarly it will be found that the ratio of the oxygen in the oxides of nitrogen, of sulphur, and of many of the metals, will be as 1, 2, 3, etc., to 1 of the other constituent.

Then came Gay-Lussac's discovery of the laws of chemical combination of gases by volume or measure. The observation made by that illustrious chemist that gases combine in volume, which are either equal or are even multiples one of the other, was a discovery equally important with that of combination by weight.

This simplicity arises from the peculiar circumstance that equal measures of gaseous elements consist of weights (their specific gravities) which stand to each other in the same ratio as their combining quantities.

Thus hydrogen combines with chlorine in equal measures to form hydrochloric acid, because, to take concrete quantities, 11 litres of hydrogen weigh 1 gramme, and 11 litres of chlorine weigh 35½ grammes; and these are the proportions in which these elements combine by weight.

On stating it conversely, weights of solid or liquid elements proportional to their combining weights assume the same volume when converted into vapour and measured at the same temperature and under the same amount of pressure. Thus 127 grammes of iodine, when heated so as to change it into a gas, occupy the same space that 1 gramme of hydrogen fills.

Another and a different kind of phenomenon is exhibited in the deportment of different bodies under the influence of heat. When different substances are made to receive heat at a uniform rate from one and the same source, it is found that their temperatures rise with very different degrees of rapidity. Or the experiment may be made by taking equal weights of the same substances and allowing them to lose a certain number of degrees of temperature, carefully noting the time occupied by both in undergoing this change. That body which changes in temperature most rapidly, whether to become hotter or colder, is said to have the smallest "specific heat." From experiments of this kind upon the different elements a series of numbers has been obtained,* which represent their respective specific heats, and the chief peculiarity of which is that when multiplied by the combining weights, they give nearly the same number in each instance; this is equivalent to saying that the capacity for heat of each element is inversely as its combining weight.

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* See a paper by the author in the Pharm. Journ. N. S. Vol. IX. p. 532.

It has been said that elements, when examined in the state of perfect gas, are found to contain, in equal volumes, ponderable quantities which are identical with those of their combining quantities. This observation applies equally to compound bodies.

The formula—

HCl represents $36\frac{1}{2}$ parts of hydrochloric acid.
H_2O ,, 18 parts of water.
H_2S ,, 34 parts of sulphuretted hydrogen.
H_4C ,, 16 parts of marsh gas.
C_2H_6O ,, 46 parts of alcohol.
$C_4H_{10}O$,, 74 parts of ether.

All these, measured at such temperatures that they are in the gaseous condition, fill the same space, and they are the quantities which represent the "units of chemical action" in the instances given. These are the proportions in which it is easy to prove by other methods, these compounds enter into combinations, or are produced by chemical decompositions. They represent what are known as the molecules of these compounds.

"There are, also, crystalline compounds, which chemistry has found to be closely analogous, which occupy, in the crystalline state, equal or nearly equal volumes.

"Among other physical properties which confirm the truth of the atomic views of molecular constitution are boiling-points. Whenever truly analogous elements are comparable in respect to boiling-points, it is found that those composed of heavier atoms boil at higher temperatures than those composed of lighter atoms. A comparison of the successive terms of the series—chlorine, bromine, and iodine—illustrates this difference very strikingly. So, also, a comparison of the several terms of the series,—oxygen, sulphur, selenium, and tellurium, and, not less so, the elements, nitrogen, phosphorus, arsenic, antimony, and bismuth.

"Now, whenever volatile organic compounds belonging to a homologous series are compared, it is found that, of two such compounds, the one having the higher molecular weight has also the higher boiling-point. The glycols present, however, an exception to this general observation.

"The melting-points of homologous organic compounds also show differences running parallel in like manner to their differences of molecular weight.

"The relative velocities of motion of particles, as shown by the processes of diffusion, afford another confirmation of the general truth of the molecular weights; for, on the one hand, it is known that heavy particles diffuse more slowly than light particles; on the other hand, a comparison of the relative velocities of movement of molecules of relative weights, previously determined upon chemical evidence, shows that the heavier molecule of chemistry is also the heavier molecule in diffusion.

"Among chemical evidences of atoms the discovery of the distinction between direct and indirect combination is worth consideration, more especially as it is independent of the quantitative comparisons which have hitherto guided us. Many elements which have never been obtained directly combined, are bound together by a third; thus we have no direct compound of hydrogen and potassium, but in potassic hydrate an atom of hydrogen is united with oxygen, and an atom of potassium is united with this same oxygen, HOK. Hydrogen in this hydrate is indirectly united with potassium, an atom of oxygen being the connecting link between them.

"What concerns us in these reactions is to see the evidence which they afford that the binding element is an atom. The very fact itself amounts to that. In potassic hydrate, oxygen is combined with hydrogen; it is also combined with potassium, but the hydrogen cannot pass off, even at a red heat, in combination with its half of the oxygen. The two halves are inseparable, and when I say that in the molecule of potassic hydrate there is a single atom of oxygen, I merely state that fact."*

It is urged by Dr. Williamson, in his recent lecture just quoted, that the objections to the atomic theory hitherto put forward have never assumed the character of open and systematic attack. This is indeed true, but it cannot be forgotten that these doubts and objections have arisen from men occupying the highest rank, not only among metaphysicians, but among chemists and physicists. That chemists generally have uttered little complaint may be ascribed to a very natural disinclination to find fault with a theory which, in one form or other, has done to their science so much good service. Even those who do not place faith in the atomic theory as a truth, are not unwilling to retain it for the sake of the facilities the application of it affords for the expression and colligation of facts.

Putting aside for the present abstract speculations as to the possibility of the existence of finite particles, we shall do best to confine ourselves to considerations which most nearly interest the chemist and physicist. I venture to offer the following examples from the category of phenomena which cannot at present be considered capable of explanation by an appeal to the doctrine of atoms. The instances I have selected are taken from the great number which might be adduced ; but, in stating them, I do so in no spirit inimical to the ordinarily received doctrine, but merely to show that our knowledge of the rationale of such phenomena is at present only imperfect. However firm our allegiance to the doctrine of atoms, it can do no harm to view it from the stand-point of an opponent.

1. The great mainstay of the belief in atoms possessing definite weight is the fact that the best known compounds present an invariable composition, which is not altered by increased or diminished pressure, temperature, and the like ; and that the proportions of the constituents in any two oxides, chlorides, sulphides, etc., of the same metal are in a simple ratio to one another.

I consider it yet remains to be more satisfactorily shown that this definite character belonging to ordinary chemical combinations passes through to the more complicated instances of which so many are known ; such, for instance, amongst others, as the following.

There are certain substances, like carbon, silicon, boron, and some of the metals, which it is well known it is next to impossible to obtain in a state of absolute chemical purity. Carbon, for example, has never, so far as I know, been obtained from any form of charcoal thoroughly purified from minute quantities of hydrogen, oxygen, or nitrogen.

If we take a piece of pure white sugar, and heat it in an open platinum capsule, it melts, catches fire, and, when the combustion is extinguished, there remains a shining brittle mass, which may be heated red-hot in the air for hours ; chlorine gas may be passed over it ; it may be boiled in various solvent liquids, and dried over again at a red-heat ; and, do what we may, the charcoal which remains holds a certain, but not fixed, quantity of hydrogen most tenaciously. Now, in the original carbonaceous compound, the elements are considered to be in a state of chemical combination ; if so, it must be admitted that the hydrogen which is retained by the charcoal is also chemically combined with the carbon therein. But the proportion of carbon and hydrogen can never be expressed by a probable atomic formula.

2. There are numerous compounds, some of which are connected with the

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* Williamson on the Atomic Theory, Journ. Chem. Soc., ser. 2, vol. vii. p. 328.

living animal or plant organism, either as products of secretion or excretion, the constitution of which we believe we understand perfectly, not only because they exhibit definite properties, but also because many of them can be artificially produced by processes of synthesis; but there are others from which these are products of disintegration, which have never been formed synthetically, nor is there any probability of their being so, and which, whilst presenting tolerably definite external characteristics, are so complex in composition, that in order to express the atomic proportion of their constituents, we are obliged to represent their molecules as built up of hundreds of atoms. When we come to such formulæ as $C_{116}H_{240}N_4PO_{22}$, or $C_{72}H_{113}NaN_{18}SO_{22}$, would it not be more candid to give up definite proportions, and admit that these may be examples which do not fit the rule?

3. The phenomena of solution can be explained only upon the assumption that some modified form of chemical affinity is the disposing influence in such cases. That attractions related to those commonly called chemical are exerted is probable, from the well-known fact that there is a sort of "elective affinity" exhibited in the action of different solvent liquids upon solid and other substances, and also that some of the solutions produced exhibit a stability, uniformity, and definiteness of character, rivalled only by those of true and undoubted chemical compounds. Examples of the latter condition are met with in the combinations of hydriodic and hydrochloric acids with water: at a certain stage of concentration, and under uniform barometric pressure, these liquids have a constant boiling-point and specific gravity. Examples of the selective power of solvents are so familiar and numerous that one will suffice here.

Water, HHO, dissolves nearly all salts; no fatty substances; few organic principles, except those of saline constitution.	Alcohol, EtHO, dissolves few salts; some fatty bodies; but chiefly crystallizable organic substances.	Ether, EtEtO, dissolves scarcely any salts; but chiefly fatty and highly carbonaceous substances.

Here are three liquids, usually regarded as possessing analogous chemical constitution; alcohol being formed from water, and ether from alcohol, by the successive replacement of the atoms of hydrogen by a hydrocarbon radicle. In proportion as the carbon increases in the solvent, so its affinity for carbonaceous substances increases; whilst, on the other hand, as the saline character of the solvent is lost (water being usually regarded as a kind of salt), so its action upon saline bodies decreases. Solutions can, of course, be prepared of any degree of dilution at pleasure.

Further illustrations of the *chemical* nature of the attractions which give rise to solution may be found in such simple and familiar experiments as the following:—If some resin be dissolved in rectified spirit, and water be then added, the whole of the resin is redeposited in the form of a precipitate. The spirit has an affinity for the resin, but a greater affinity for the water; it therefore parts from the former in favour of the latter, and the resin being insoluble in the new compound, is thrown down again.

If alcohol is mixed with water, the resulting compound possesses a density greater than the mean of the densities of the two liquids; this shows that contraction of volume has taken place; consequently there must be a bond between them more intimate than that of mere mechanical mixture.

4. There are a few very interesting bodies, among the best known of them being the graphitic acid discovered by Brodie, the constitution of which seems to bear upon the subject under discussion. Graphitic acid is prepared by the action of powerful agents of oxidation upon that variety of carbon only which is known as "graphite" or "blacklead." The combining weight

of the carbon in this compound is reckoned as 33. Now it is curious that the "atomic" weight, calculated from the specific heat* of graphite, closely approximates to this,—it is about 32. Here is a number which, if at all to be relied upon, is irreconcilable with the atomic hypothesis, no even number of atoms, each weighing 12 (or even the old number 6), would give, when united together, an aggregate of 32 or 33. There are indications, though not yet well-established, that there are differences of a similar kind in the atomic weight of several other elements (silicon, sulphur, phosphorus, and probably antimony and others) when examined under the different forms known as their allotropic modifications.

5. The influence which quantity† exerts upon chemical reactions, is remarkable in almost every experiment that can be devised; in some instances it amounts to a power which is capable of determining the manner of a reaction even apparently in opposition to ordinary affinities. The chlorides of bismuth and antimony are deliquescent bodies, very soluble in a *small* quantity of water, but decomposed by a larger quantity. The perchloride of antimony has the formula $SbCl_5$; by the action of a considerable quantity of water it gives an oxide and hydrochloric acid.

$$2\,SbCl_5 + 5H_2O = Sb_2O_5 + 10\,HCl.$$

What we have to pay attention to in such examples is, the fact that if the experiment be tried with the weights represented in the symbolic equations, the decomposition will not be found to take place.

For instance, if $2\,SbCl_5 = 599$ parts, and $5\,H_2O = 90$ parts, be mixed together, the result will be a crystalline mass; and even if a further addition of water be made, the decomposition does not occur. A large and indefinite quantity of water is requisite to bring it about. Such phenomena were known long ago, when the atomic theory was first propounded, and were used as arguments against it by its opponents. One eminent chemist even thought it possible that quantity might compensate for feebleness of chemical attraction, so that the less energetic a body was in its affinities, the smaller its combining weight. This view was of course not long retained as a general theory of chemical combination. These facts, however, offer an unsolved problem up to the present day; for though I am not ignorant that explanations have been attempted, they do not appear to me to dispel the difficulty.

6. Leaving now chemical considerations and passing to an entirely different form of argument, I quote the following paragraphs, written by the late Mr. Faraday in 1844. Faraday, it must be remembered, was not only a physicist, but a chemist.

"The view of the atomic constitution of matter, which I think is most prevalent is, that which considers the atom as something material, having a certain volume upon which those powers were impressed at the creation, which have given it from that time to the present the capability of constituting when many atoms are congregated together into groups,—the different substances whose effects and properties we observe. These, though grouped and held together by their powers, do not touch each other, but have intervening space, otherwise pressure or cold could not make a body contract into a smaller bulk, nor heat or tension make it larger; in liquids these atoms or particles are free to move about one another, and in vapours or gases they are also present, but removed very much further apart, though still related to each other by their powers. If the view of the constitution of matter referred to be correct, and I may be allowed to speak of the particles of matter and of the space between them [in water or in the vapour of water for instance] as two different things, then space must be taken as the only continuous part, for the particles are considered as separated by space from each other. Space will permeate all masses of matter in every direction like a net, except that in place of meshes it will form cells isolating each atom from its neighbours, and itself only being continuous.

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* See page 414.

† Important and perhaps more conclusive experiments have been made upon gaseous mixtures by Bunsen, and upon mixed solutions by Débus and others.

"Then take the case of a piece of shellac, a non-conductor, and it would appear at once from such a view of its atomic constitution that space is an insulator, for if it were a conductor the shellac could not insulate, whatever might be the relation as to conducting power of its material atoms; the space would be like a fine metallic web penetrating it in every direction, just as we may imagine of a heap of siliceous sand having all its pores filled with water; or as we may consider of a stick of black wax, which, though it contains an infinity of particles of conducting charcoal diffused through every part of it, cannot conduct, because a non-conducting body (a resin) intervenes, and separates them one from another like the supposed space in the lac.

"Next take the case of a metal, platinum or potassium, constituted according to the atomic theory in the same manner. The metal is a conductor; but how can this be, except space be a conductor? For it is the only continuous part of the metal, and the atoms not only do not touch (by the theory) but must be assumed to be a considerable way apart. Space, therefore, must be a conductor, or else the metals could not conduct, but would be in the situation of the black sealing-wax, referred to a little while ago.

"But if space be a conductor, how then can shellac, sulphur, etc. insulate, for space permeates them in every direction? Or if space be an insulator, how can a metal or other similar body conduct?

"It would seem, therefore, that in accepting the ordinary atomic theory, space may be proved to be a non-conductor in non-conducting bodies, and a conductor in conducting bodies, but the reasoning ends in this, a subversion of that theory altogether; for if space be an insulator it cannot exist in conducting bodies, and if it be a conductor it cannot exist in insulating bodies. Any ground of reasoning which tends to such conclusions as these must in itself be false."*

But there has been offered to us a way for escape from the contradictions into which we are led by this manner of handling the ordinary atomic theory. It is open to conjecture, that matter may be continuous,—of a homogeneous not heterogeneous texture,—elastic, not composed of hard particles, and, being continuous, consequently subdivisible without limit. According to this notion there may be *masses* of any conceivable smallness, but so long as they possess magnitude these are not *atoms*, *i. e.* indivisibles. The two theories differ in this respect,—the one teaches the existence of particles which are very small, but still composed of parts, and possessing a determinate and not difficultly-imaginable magnitude. They may be compared to a heap of cannon balls, or any other symbol selected from ordinary objects. The other theory disregards the shell of the imaginary spheres, and treats only of their centres. These points are presumed to be the centres of action of radiant forces, under some conditions attractive, under others repulsive.

Are these two theories altogether incompatible with each other? It certainly seems as difficult to dispense with the assumption of atoms as it is to manage them in their assumed combinations. But would it not be allowable to figure these atoms not as weighing fractions of ordinary units of weight; may we not say that they hold the place of the "centres" of force just referred to, that they are, in fact, *infinitely* small?

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* Phil. Mag. vol. xxiv. p. 136.

Supposing such a modification admitted, the usual atomic theory becomes nearly identical with the theory of Boscovich. Atoms, on this view, occupy a position with regard to masses analogous to that of mathematical points, by the juxtaposition of which lines, surfaces, and solids are generated. A line, it is obvious, may be divided by a ruler or other mechanical means into any number of shorter lines, but these are still made up of many points. The analysis of a line into its constituent points can only be effected mentally; it is, however, not a very easy thing even to imagine a point, because it cannot truly be compared to anything we have ever seen. So with atoms, the matter of bodies. Neither the points nor the atoms have any real, tangible existence as bodies, but we are not on that account precluded from reasoning upon them as though they had. Moreover, we do not always construct theories because we believe them to represent faithfully what is actually the case, to stand in the position of absolute truths, but because they enable us to co-ordinate phenomena, and bring within reach many things which would otherwise lie out of the sphere of our limited intellectual capacity. This hypothesis requires the absolute weights of the atoms to be reduced proportionately to their magnitude; they must be assumed infinitely small; nevertheless, though infinite, they may bear to each other the ratios which we commonly express as atomic weights. It may seem an anomaly that masses should be acted upon by gravity—that is, have weight—whilst their constituent parts have not; but the anomaly vanishes if we allow that infinite smallness is not absolutely nothing.

Such a view of the constitution of matter seems to me to be more in harmony with the general plan of nature, so far as science has at present been enabled to trace it, than any based upon the exclusion of the idea of infinite divisibility. It allows us to form at least rough conjectures as to the mode of action and reaction subsisting, not only between the different forces themselves which are known to affect matter, but also between those forces and matter itself as the subject of their operations. No corpuscular hypothesis, as we may distinguish Dalton's atomic theory, does, nor can, elucidate, however crudely, the *modus operandi* of such as are denominated imponderable agents, in their relations to ordinary ponderable matter. I can see no way of explaining in a rational manner processes of photography or the action of heat in promoting chemical combinations, upon the assumption of finites as the objects and infinites as the agents in the operation. But if we superadd to the ordinary hypothesis the conception of infinity extended to the weight as well as magnitude of atoms, we reduce to a minimum the difficulty of correlating our ideas of ordinary matter with those of the mysterious agencies, light, heat, and the other "physical forces."

Of recent years our notions of the nature of the phenomena which we ascribe to these invisible agents have gradually suffered complete revolution. It is less than a century ago when the opinion was very generally held among men of science, that the phenomena of heat were due to the existence of a peculiar substance or form of matter called "caloric." According to this view, bodies became heated by absorbing caloric; they became cold by losing caloric; radiation of heat was the shooting out of particles of caloric; the phenomena of specific and latent heat, in like manner, were thought to be occasioned by a varying tendency to a kind of combination between the particles of ordinary matter and those of this subtle material, caloric.

In this our time, all these changes are universally believed to be caused by *motion*. Vibratory motion of the particles of bodies is supposed always to be going on; increase the rapidity of the vibration, and you get what is called increase of temperature—the body becomes hotter; diminish the rapidity, and you get depression of temperature, or cooling. Allow these vibrations to assume a rhythmical order, to take the form of waves, and the propagation of heat by radiation is accounted for.

It was at a period still less remote, no more than about forty years ago, that the old "emission theory" of light came to be displaced from the convictions of philosophers. It had been held since the time of Sir Isaac Newton that there existed minute particles of excessive tenuity, which, darting out from luminous bodies through space and through transparent media at the rate of something like 160,000 miles a second, gave rise to the phenomena of light. But in consequence of certain phenomena being discovered, the existence of which could not be explained by the aid of this theory of corpuscles, attention was drawn more forcibly to the "theory of undulation," which then almost at once supplanted it, and has held its ground since. Belief is now fixed, not in the existence of rapid-shooting particles, but in waves formed by the rhythmical vibrations of an ether which is supposed to exist throughout space. Whisperings have not been wanting that this "ether" may somehow be connected with ordinary matter, either as the *materia prima*, out of which all things were in the beginning educed, or perhaps, as the ruins into which the clumsy molecules of gravitating matter may have tumbled. That there is something possessing inertia diffused through the interplanetary spaces seems likely from the fact known to astronomers that the motion of certain comets is continually diminishing.

In the early days of the science of electricity, all the phenomena manifested by this wondrous agent were ascribed to the existence of a fluid; afterwards the hypothesis of two fluids was required. The existence of fluids in electrically excited bodies has, however, been for some time regarded as a myth. From the fact that electricity and magnetism are mutually convertible, and these again producible from, and reducible to, heat, light, or *ordinary motion;* and taking into account the circumstance that they are unknown apart from ordinary matter, it has been conjectured that these "fluids" may in reality be a *motion* of a peculiar kind existing in the particles of bodies. Heat, light, electricity, and magnetism are then motion.

By an extension of the idea, superposed upon a revival of the long-cherished notion of the universality and unity of origin of matter, "it is conceivable that the various kinds of matter now recognized as different elementary substances, may possess one and the same ultimate or atomic molecule, existing in different conditions of movement." * These are the words of a philosopher, unhappily for science, now no more; and they were written at the conclusion of a life which had been devoted to the study of molecular dynamics. If we accept them, we arrive at a generalization as grand as it is simple in conception, as universal as it is obedient to the requirements of science.

The phenomena of which we are the witnesses, and which in our own bodies we serve to exemplify, are continually reminding us that all in the universe is change. Change, we may henceforth believe, is motion.

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* Graham: "Speculative Ideas respecting the Constitution of Matter," Journ. Chem. Soc. vol. xvii. p. 368.

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